SO Conf Paper/IVHM

24P

Integrated Vehicle Health Management (IVHM) Activities at Kennedy Space Center

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Integrated Vehicle Health Management

IVHM

Integrated Vehicle Health Management

Discussion Topics

- Technology Goals & Objectives
- Background
- Current Status
- Major Accomplishments
- Near Term Plans
- Contact Info

- **Overall Program Goals**
  - Substantially reduce the technical, programmatic and business risk associated with development of a safe, reliable and affordable 2nd Generation Reusable Launch Vehicle (RLV)

- **IVHM Goals**
  - Develop and integrate the technologies which can provide a continuous, intelligent, and adaptive health state of a vehicle and use this information to improve safety and reduce costs of operations

Now	Near Term	Future
Maintain	Monitor	Management
Human Control	Distributed Control	Autonomous Vehicle
Reporting	Processing	Reacting
Analyze	Diagnosis	Prognosis
Sensors	Intelligent Sensing	Integrated Sensor Suites
Component	Subsystems/Vehicles	System

Integrated Vehicle Health Management

Technology Goals & Objectives

- **KSC IVHM Goals**
  - **Reduce ground and flight operations costs for vehicles and payloads**
    - Automated in-situ vehicle checkout
    - Ground maintenance on exception-only basis
    - On-board failure isolation = reduced ground troubleshooting efforts
    - Automated servicing and checkout
    - Reduced size of flight and ground controller teams
    - Standardized payload interfaces
    - Containerized payloads with off-line testing
  - **Improve Safety & Reliability**
    - Faster identification of failures
    - Prediction of failures
    - Reduced human error through pre-programmed responses
    - Increased redundancies
    - Use of modern non-intrusive sensors in high criticality systems

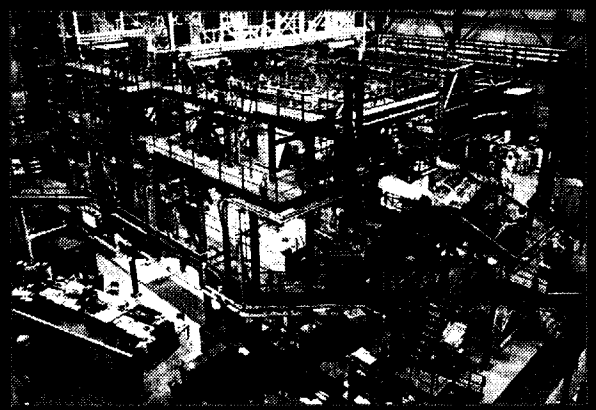
- **KSC IVHM Focus Areas**
  - **Flight and Ground-based Test Beds**
  - **Advanced Sensors (Hazardous Gas Detection, Wireless)**
  - **Evolved Control Room Technologies with Advanced Applications**
  - **Informed Maintenance (IM)**
    - Diagnostics / Prognostics
    - Automated Maintenance Scheduling
    - Automated Logistics Coordination (People/Parts/Paper)
    - Paperless Documentation
    - Data Mining

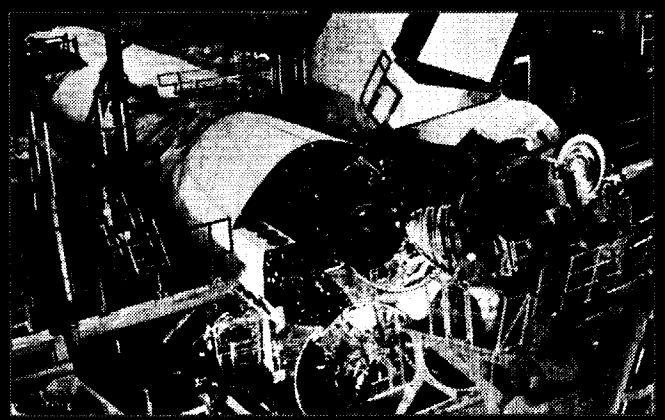
- 1st Generation Ground Operations Reality
- 2nd Generation Ground Operations Vision
- 3rd Generation Ground Operations Vision

Background

1st Generation Ground Operations Reality

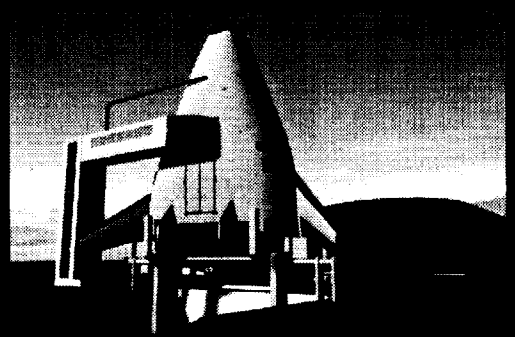
- Best described as manual integration of planned and unplanned operations
- Planned - checkout based on FMEA, R&R of limited life components, servicing
- Unplanned - IFAs and other failures - involves removals for access, troubleshooting, failures and copper path retest
- Paper intensive
- Logistics coordination (people/parts/papers) attempts to use statistics of 4 vehicle fleet, but largely manual
- Conflicts identified by representatives of subsystem engineering, shop, quality, other at scheduling meetings
- Schedules adjusted manually every shift - move magnet bars on wall!





2nd Generation Ground Operations Vision

- Described as semi-automated
- Ground systems highly integrated with flight systems from day one of design phase
- Extensive use of highly automated test and checkout equipment
- Paperless work environment
- Informed Maintenance implemented
  - Maintenance schedules automatically generated and updated taking into account planned and unplanned operations
  - Flight and ground based diagnostic/prognostic health algorithms integrated and use multi-mission data mining
  - Extensive use of intelligent applications for engineering advisories for near real-time launch and ground operations decisions
  - Ground receives periodic health summary data from flight vehicles
  - Logistics coordination and test requirement determination statistically oriented



3rd Generation Ground Operations Vision

- Described as fully automated
- Informed Maintenance implemented with the following considerations
  - Use scaled up elements of 2nd Generation IM system
  - Very large fleet and very high launch rate - large number of component health tracking down to serial number level
  - Maintenance "at the gate" in terms of hours by very small team - rapid routing and staging of proper skilled personnel and equipment as well as procedures
  - "3rd Gen" diagnostic/prognostic health algorithms and applications for engineering advisories for near real-time launch and ground ops decisions

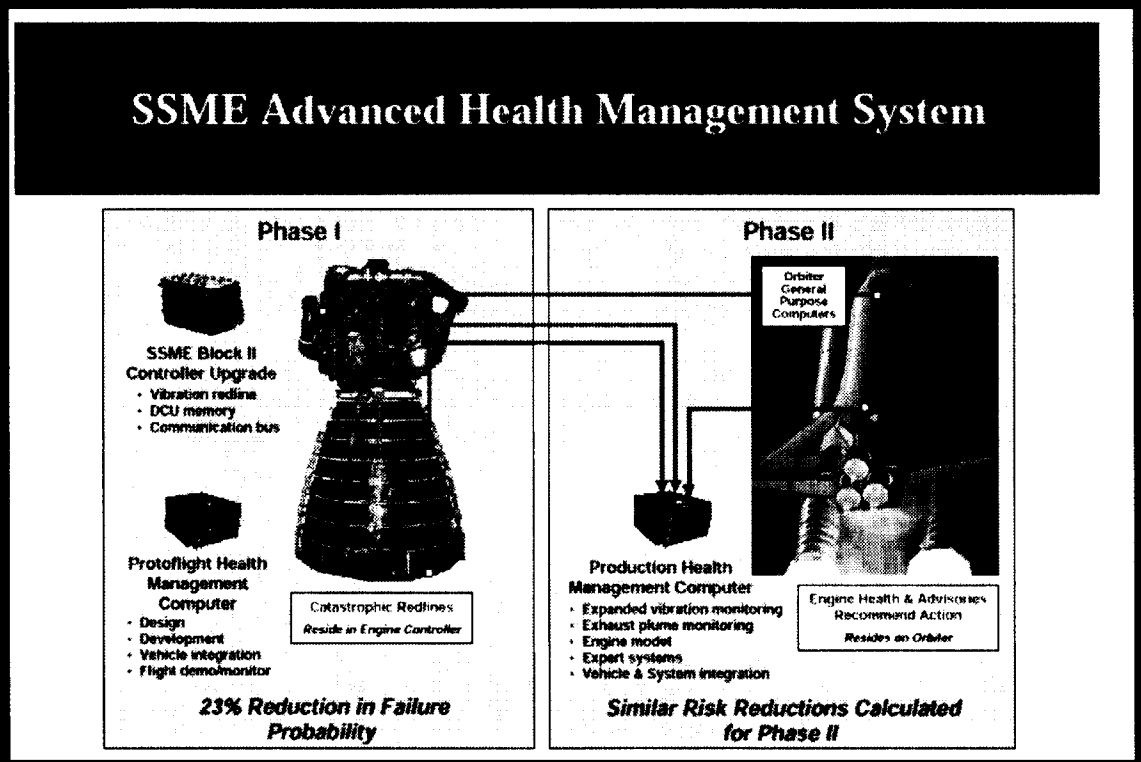
- SSME HMS/OPADS
- X-34 NITEX
- X-37 IVHM and IM
- X-38 DARTH
- CLCS
- iTPS
- PHARM
- REMA

Integrated Vehicle Health Management

Current Status

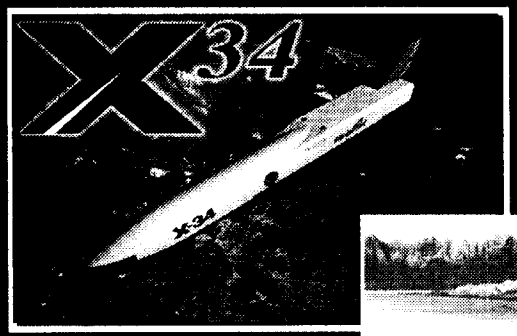
♦ Space Shuttle Main Engine Health Monitoring System (SSME HMS)

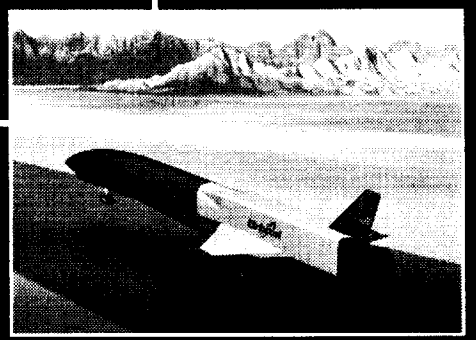
- **Optical Plume Anomaly Detection System (OPADS) Flight Experiment**
  - Planned for three flights, first mid-2002

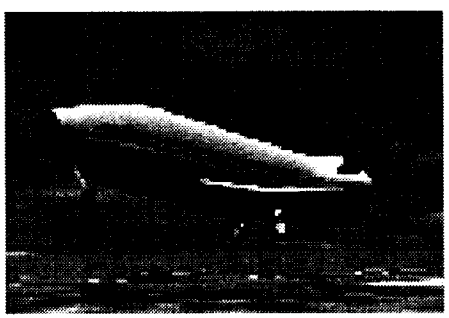


★X-34 NASA IVHM Technology Experiment for X-vehicles (NITEX)

- Propulsion system health monitoring experiment
- Fly as payload on X-34
- Multiple flights (first late 2001)
- Develop prognostication







★X-37 IVHM and IM

- Electro Mechanical Actuator & Power Systems Health Monitoring Experiment
- Embedded in vehicle avionics
- Operate during B-52 drop tests (1/2002) and Shuttle/ELV payload (11/2002)
- Informed Maintenance

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Current Status

★X-38 Crew Return Vehicle (CRV)

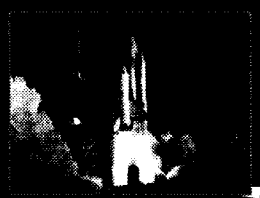
- Provide interface between X-38 vehicle and Orbiter
  - X-38 has Device to Allow Return Telemetry Handling (DARTH)
  - Orbiter has Vehicle Analysis And Data Recording (VADAR)
- Fly as Space Shuttle payload on STS-113 (2/2002)

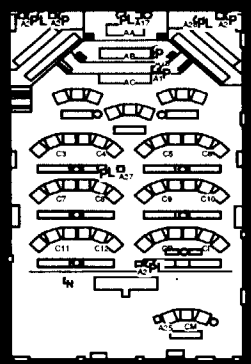
X-38

♦ Checkout and Launch Control System (CLCS)

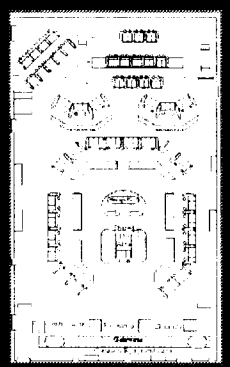
- Complete replacement of 1970s era Launch Processing System in work, first launch late 2002

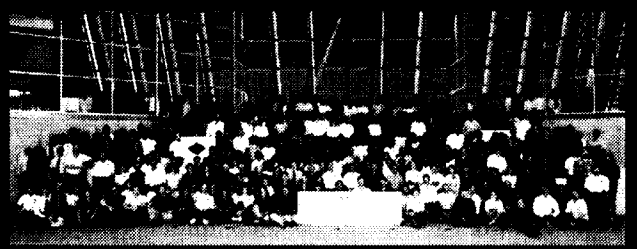
OLD (LCC) Single Workstations





NEW (OCR) CLCS Work Groups





Integrated Vehicle Health Management

Current Status

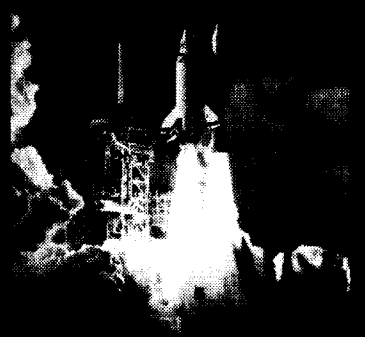
- intelligent Thermal Protection System (iTPS)
  - ARC-led effort, KSC role is to develop Space Shuttle flight experiments
- Informed Maintenance - Predictive Health And Reliability Management (PHARM)
  - Boeing KSC and NASA KSC
  - Develop an end-to-end Informed Maintenance system, planned completion 12/2000
  - Plan to integrate into X-34, X-37 and Spaceport Technology Test Complex
- Reconfigurable Electro-Mechanical Actuator (REMA)
  - Oklahoma State University and NASA KSC
  - Develop parallel neural network control systems for EMA operated aerosurface
  - Previous work was neural network for solenoid valve signature recognition

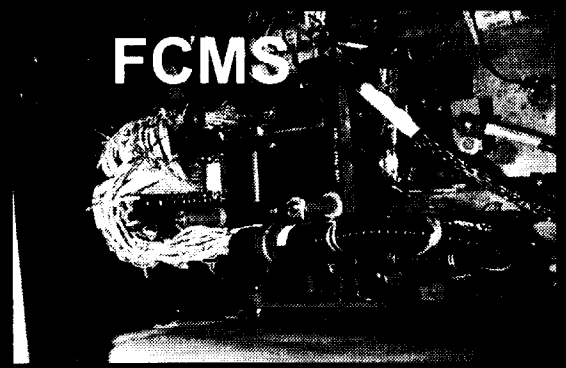
Current Status

- IVHM HTDs
- FCMS
- OMS/RCS IVHM Test Bed
- u WIS
- Wireless VJ Sensor System
- SOCC

Major Accomplishments

Space Shuttle IVHM HEDS Technology Demonstrations





Example Problems

- Fuel Cell single cell volt test
- Aft & PLB haz gas detection
- Crit 1 GOX temp probes
- MPS LH2 FCV testing
- SSME inspections
- Radiator inspections
- MPS pneumatic system testing
- ET/Orbiter plate gap testing

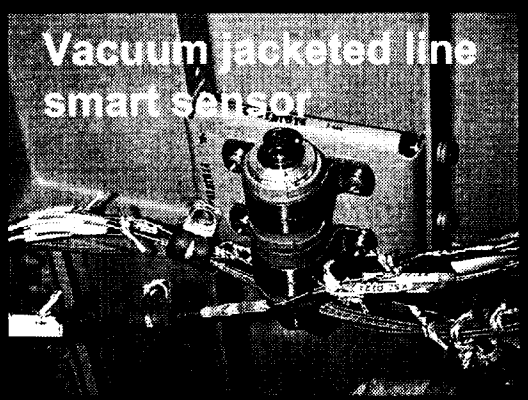
Solutions

- ✓Fuel Cell Monitoring System
- ➢Smart H2 & O2 sensors + FBG FO
- ➢Use non-intrusive sensors, wireless
- ➢Hall Effect sensors w/ NN
- ➢SSME HMS, FFT accels, OPADS
- ★ Acoustic emission sensors
- ➢Helium leak detection sensors
- ➢Delta Press sensors

✓= implemented ➢= demo on HTD ★ = needs development

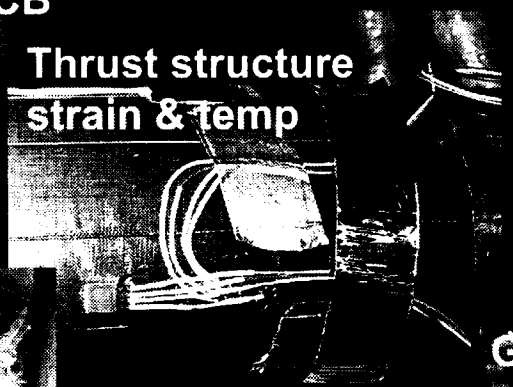
Space Shuttle IVHM HEDS Technology Demonstrations (cont'd)

John Glenn with custom CB



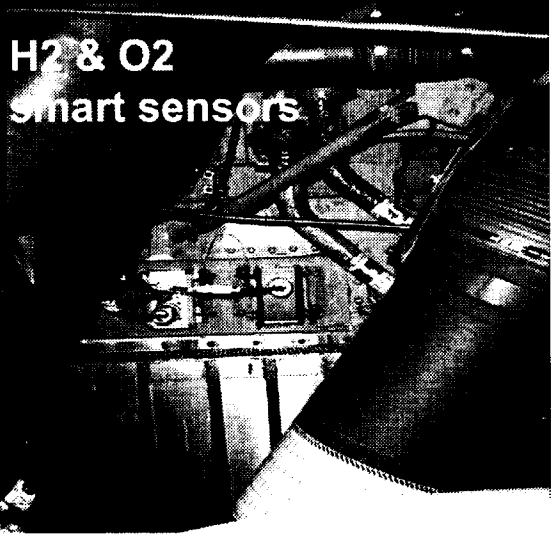
Conduction cooled ATR

HTD-2 ATR & RHNs



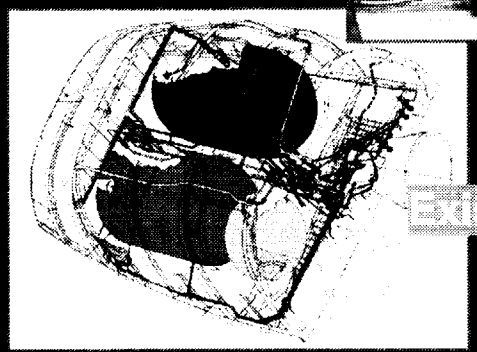
ET/QRB plate gap
delta P

GOX skin temps



Space Shuttle OMS/RCS Helium System IVHM Test Bed

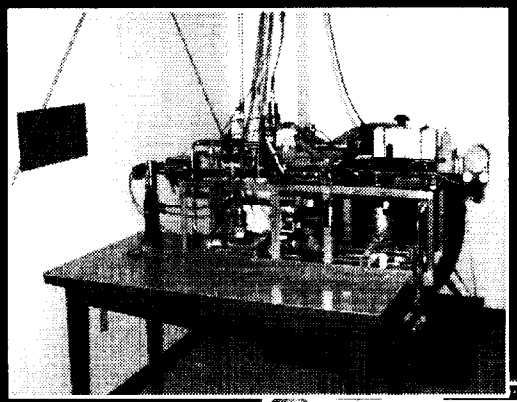
- Service and test 8 systems in parallel

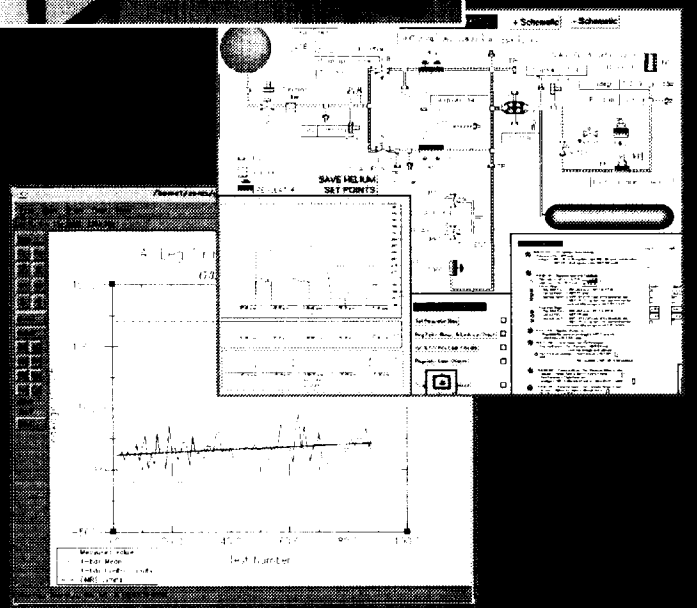


Shuttle OMS/RCS

Existing GSE

Pneumatic System IVHM Test Bed with Automated GSE





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Major Accomplishments

- **Micro Wireless Instrumentation System (u WIS)**
  - NASA JSC and KSC effort
  - Two configurations: Micro-sensor/recorder packages and wireless sensors/laptop package
  - Flew STS-96, STS-101, STS-106, International Space Station
- **Wireless Vacuum Jacketed Line Sensor System**
  - Spin-off of IVHM HTD technology
  - University of Florida, Boeing KSC and NASA KSC
  - For use at Space Shuttle Launch Complex 39
- **Florida Spaceport Authority Space Operations Control Center (SOCC)**
  - Boeing KSC effort
  - Funded by state of Florida
  - Can support commercial payloads and launchers

Major Accomplishments

- STTC
- MMS
- IHGDS
- APHARM
- ICS

Integrated Vehicle Health Management

Near Term Plans

- **Spaceport Technology Test Complex (STTC)**
  - Develop rapid servicing and checkout technologies for "Iron Rocket" (non-flight RLV) – target 24 hour turnarounds
  - Partnership with industry, academia, other NASA Centers
  - Serve as test bed for maturing RLV technologies through rigorous multiple cycle testing in operational environment – even to the point of failure
  - Also develop new LC-39 LOX pumps, replacement Space Shuttle Orbiter LH2 Recirculation Pumps and other large-scale industrial cryogenic components
  - In addition, provide hands-on training for Space Shuttle technicians, quality control specialists, engineers as well as industry and academia

- **Miniature Mass Spectrometer (MMS)**
  - Jet Propulsion Laboratory, NASA JSC and NASA KSC effort
  - Develop hand-held device for post-EVA toxic vapor detection and clean-up while still in airlock prior to entering Space Shuttle or International Space Station

Near Term Plans

- **Intelligent Hazardous Gas Detection System (IHGDS)**
  - University of Florida, Boeing KSC and NASA KSC effort
  - Develop on-board leak localization system using mini-mass spectrometers (leveraged from JPL and others' work) and/or smart sensors (leveraged from Bantam/GRC/MSFC/KSC work)
  - Develop complex flow circulation models for algorithms and optimal sensor placements
  - Develop 1/5 scale Orbiter aft compartment for model validation
  - Space Shuttle flight experiments planned

- **Informed Maintenance – Advanced Predictive Health And Reliability Management (APHARM)**
  - Scale-up PHARM efforts into 2nd and 3rd Generation IM system
  - Leverage Phase II SBIR - Intelligent Automation, Inc. for 3 dimensional neural network visualization technology

- **Intelligent Checkout Systems**
  - Automated video, communication and telemetry switching and retest
  - Virtual control rooms for remote commanding and monitoring

Near Term Plans

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